

(12) **United States Patent**
Ashida et al.

(10) **Patent No.:** **US 11,653,573 B2**
(45) **Date of Patent:** **May 16, 2023**

(54) **MAGNETIC DOMAIN WALL MOVEMENT ELEMENT AND MAGNETIC RECORDING ARRAY**

(58) **Field of Classification Search**
CPC H01L 43/02; H01L 27/228; G11C 11/161
See application file for complete search history.

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 212 days.

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(21) Appl. No.: **17/039,244**

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(22) Filed: **Sep. 30, 2020**

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(65) **Prior Publication Data**

US 2021/0098690 A1 Apr. 1, 2021

Primary Examiner — Shih Tsun A Chou

(30) **Foreign Application Priority Data**

Oct. 1, 2019 (JP) JP2019-181361

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(51) **Int. Cl.**

H10N 50/80 (2023.01)
G11C 11/16 (2006.01)
H10B 61/00 (2023.01)

(52) **U.S. Cl.**

CPC **H10N 50/80** (2023.02); **G11C 11/161** (2013.01); **H10B 61/22** (2023.02)

(57) **ABSTRACT**

A magnetic domain wall movement element includes a wiring layer containing a ferromagnetic material, a non-magnetic layer in contact with the first surface of the wiring layer, a first conductive layer connected to the first surface of the wiring layer and containing a ferromagnetic material; and a second conductive layer connected to the wiring layer at a distance from the first conductive layer. A first part of the connection face of the first conductive layer is directly connected to the wiring layer, and a second part of the connection face other than the first part is connected to the wiring layer via the non-magnetic layer.

21 Claims, 8 Drawing Sheets

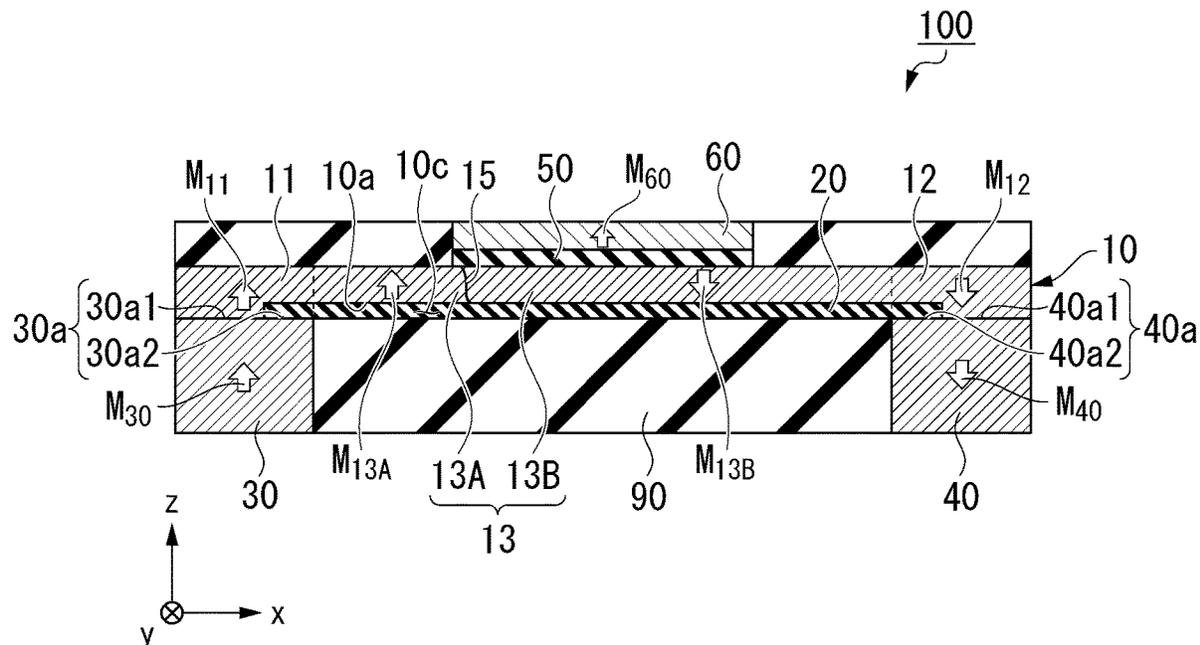


FIG. 1

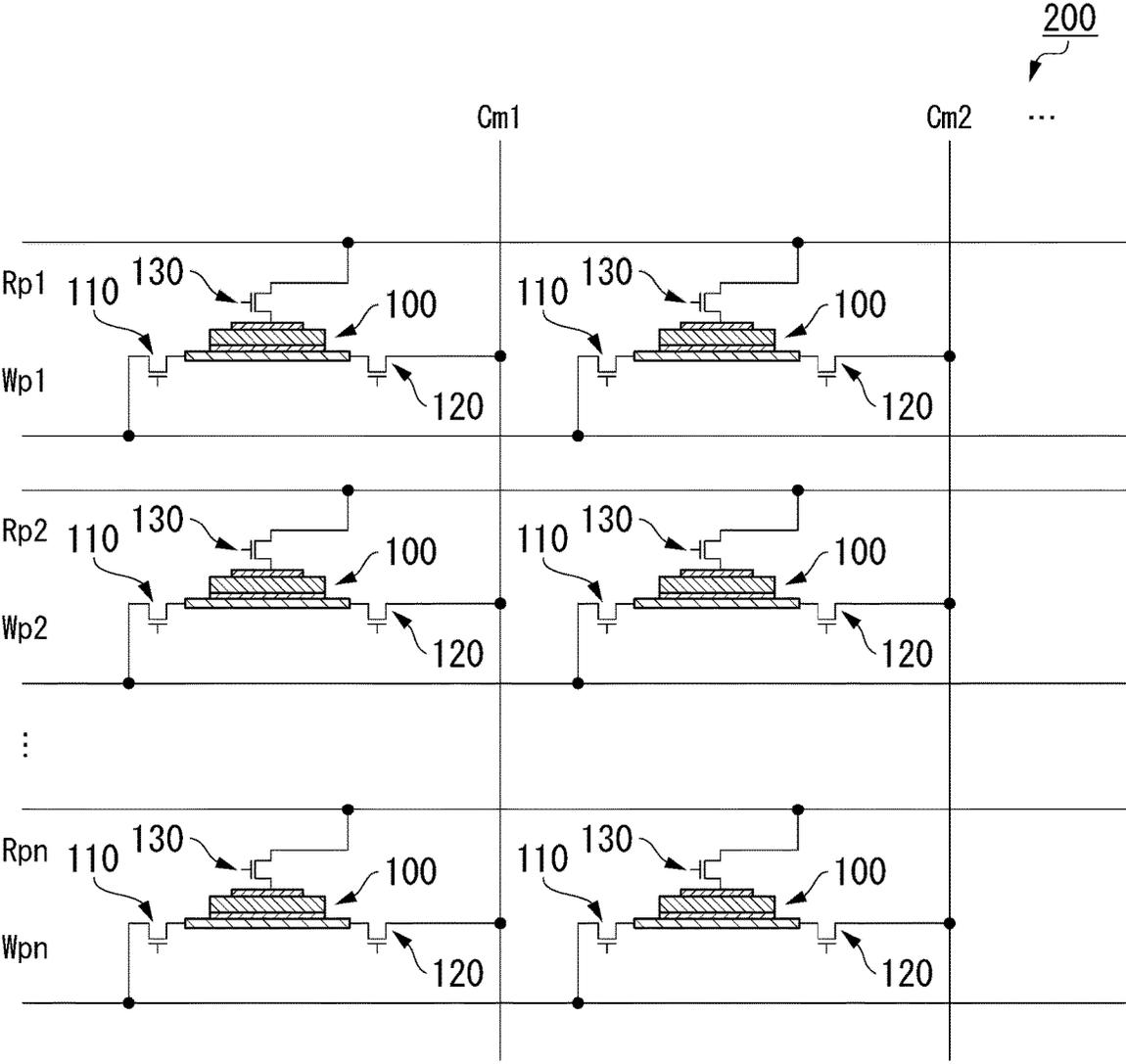


FIG. 2

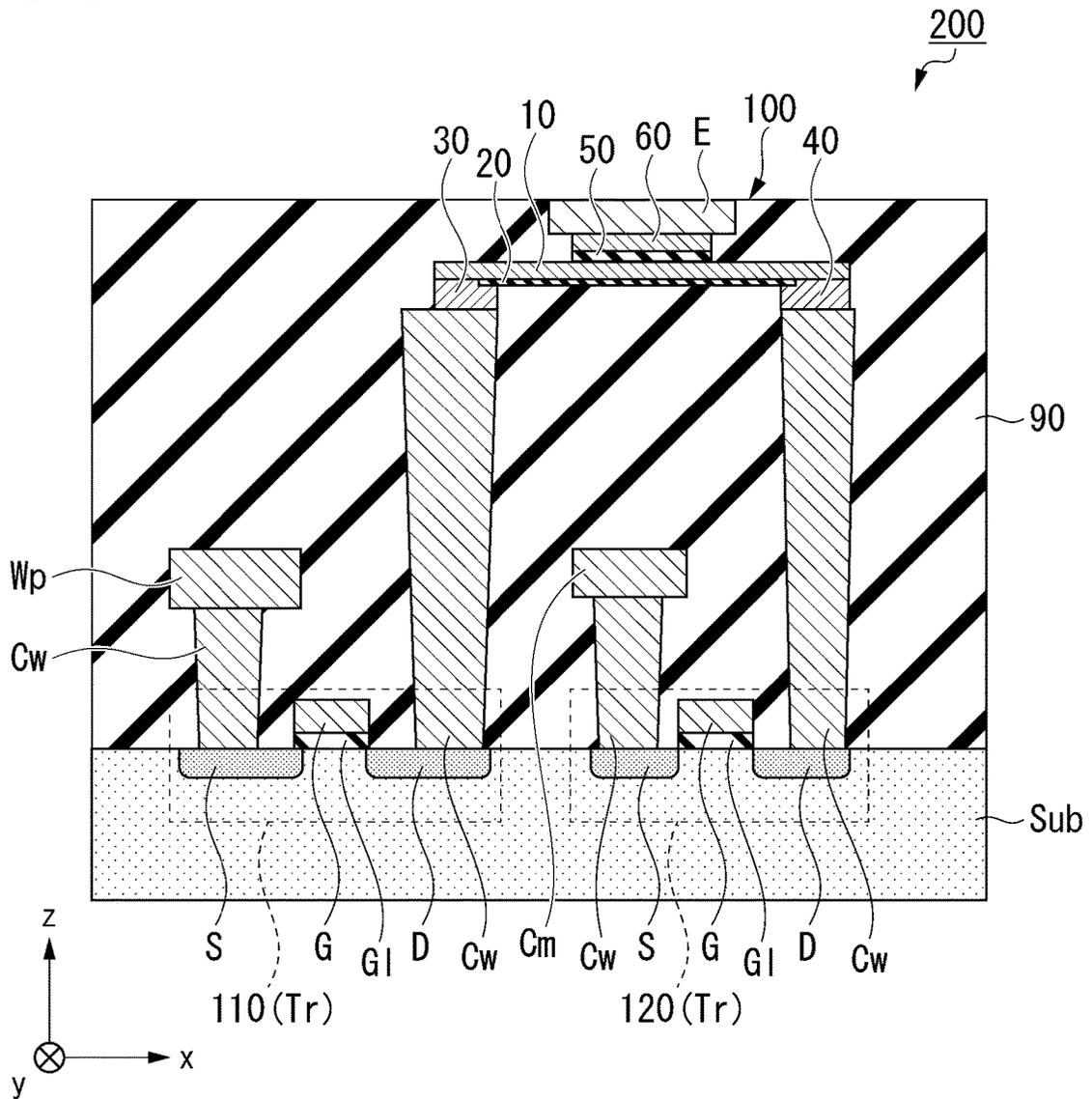


FIG. 3

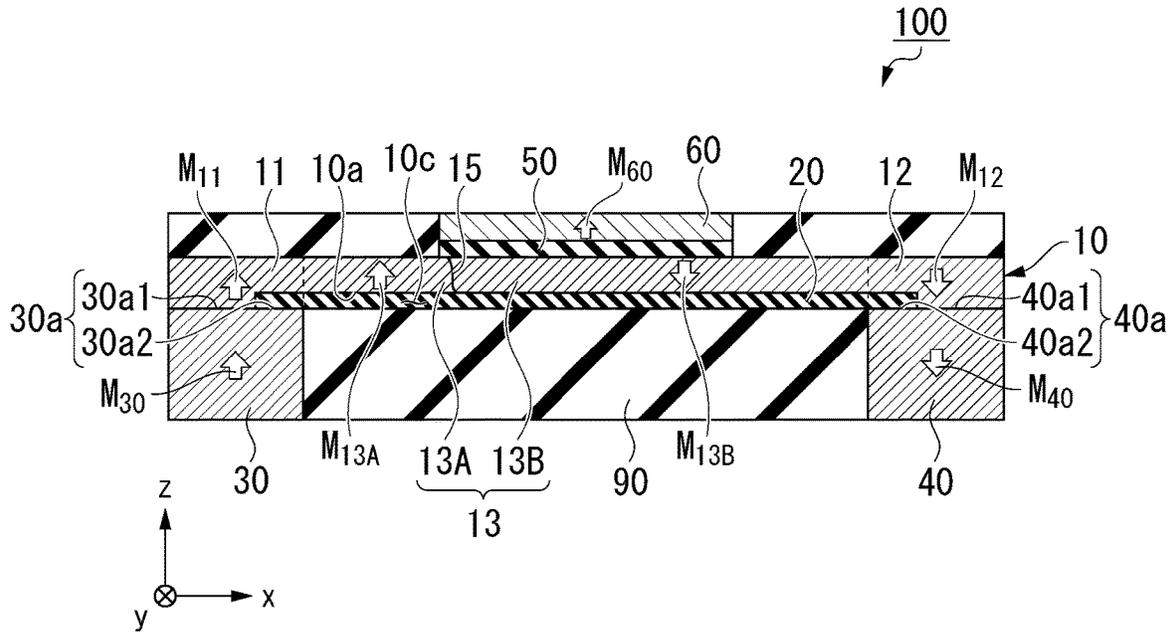


FIG. 4

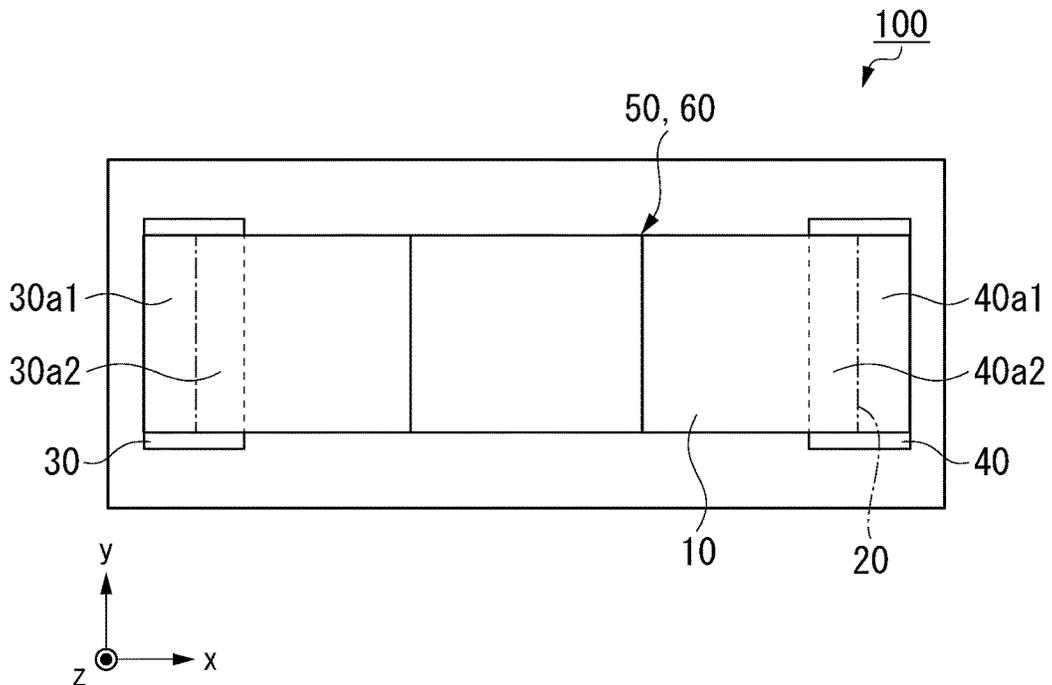


FIG. 5

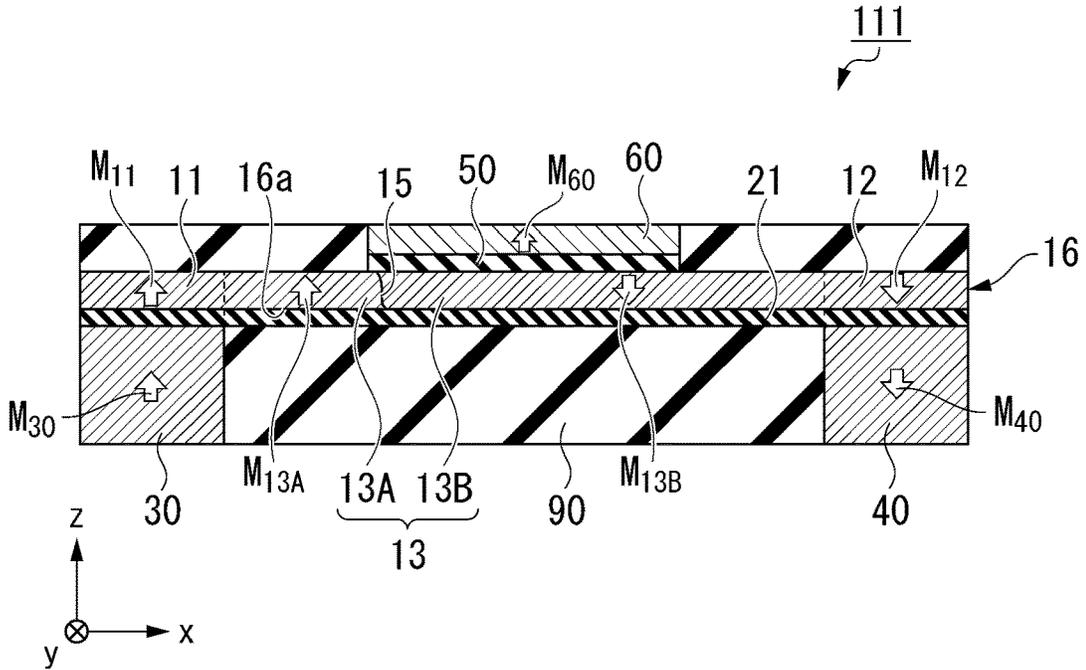


FIG. 6

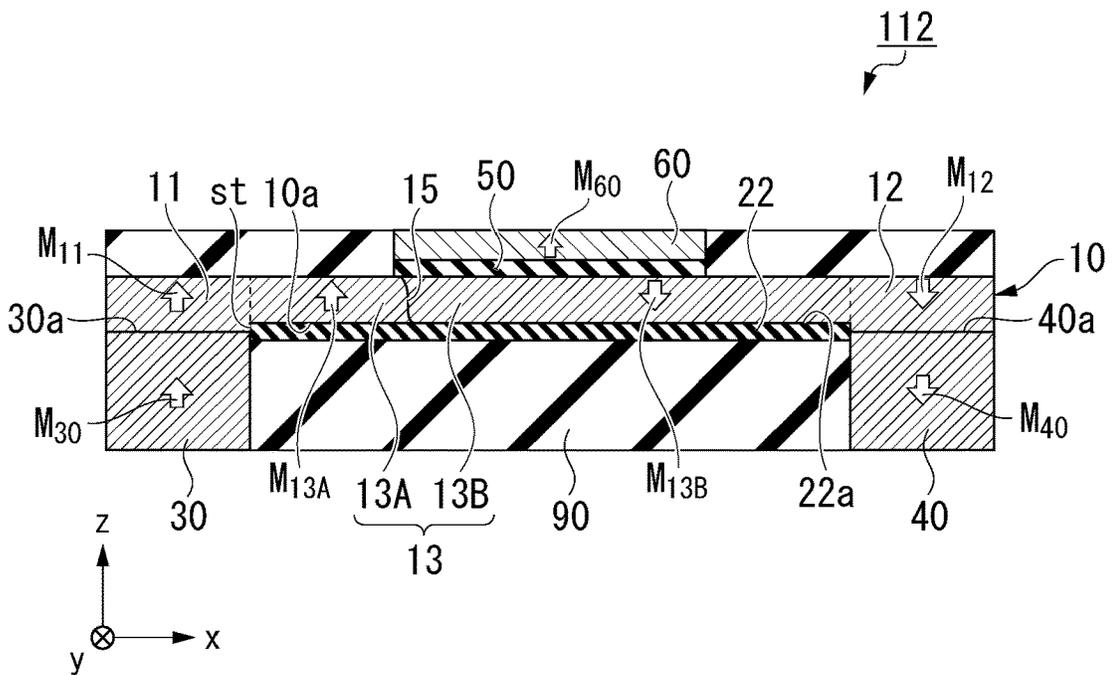


FIG. 7

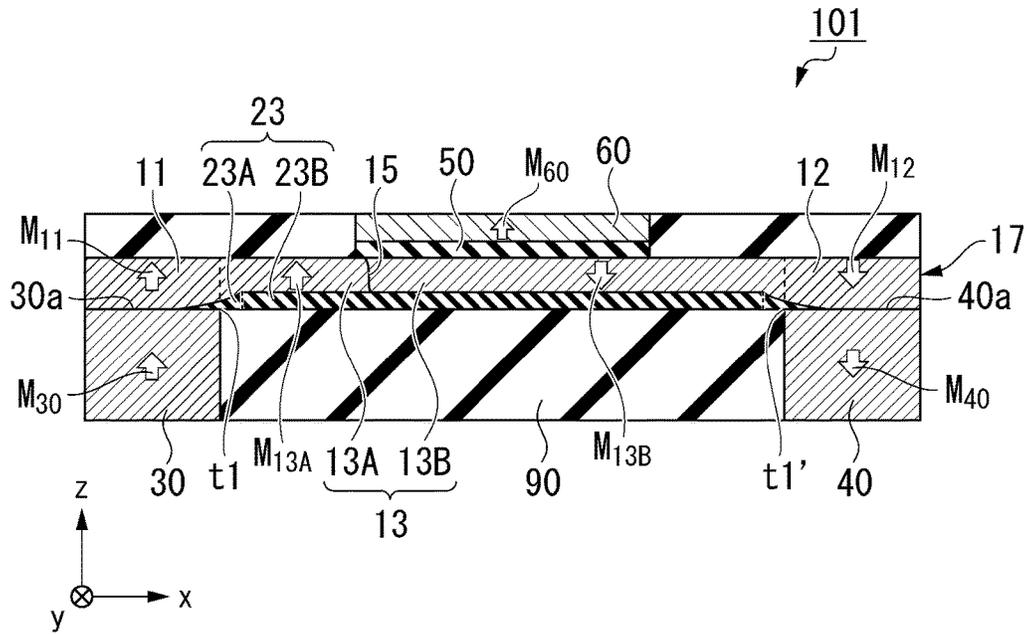


FIG. 8

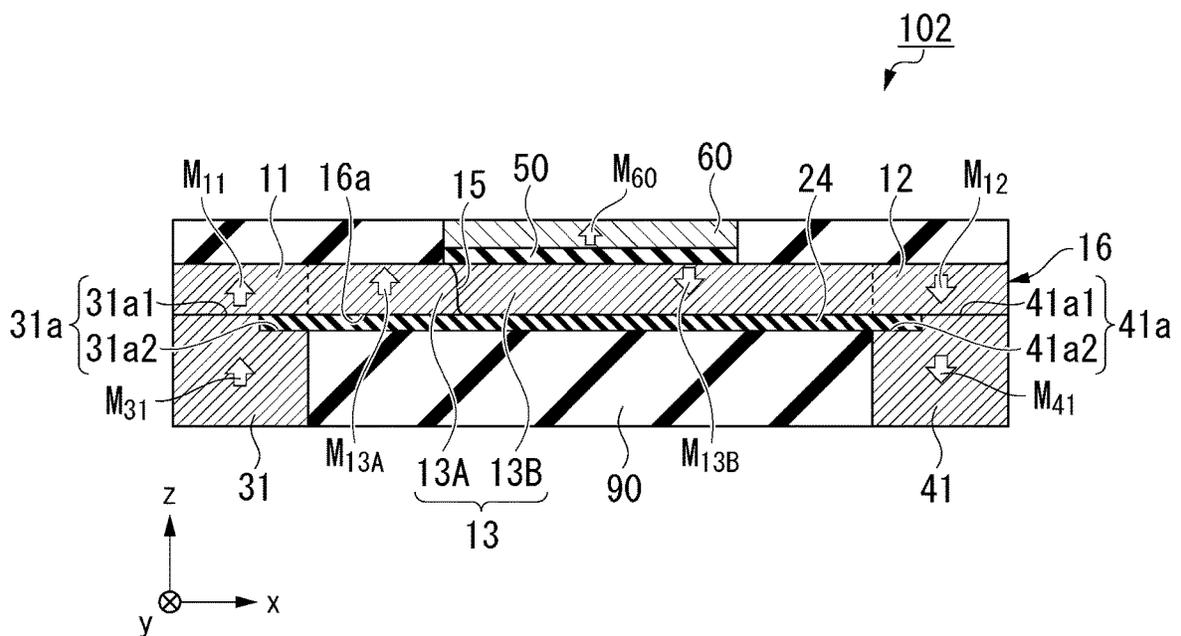


FIG. 9

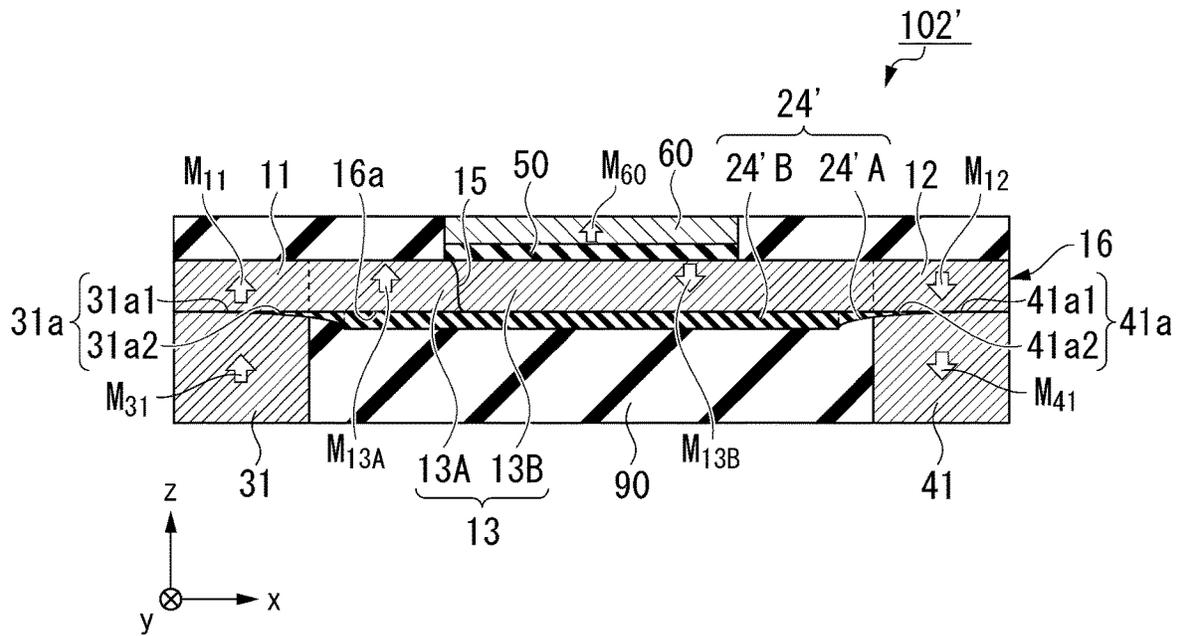


FIG. 10

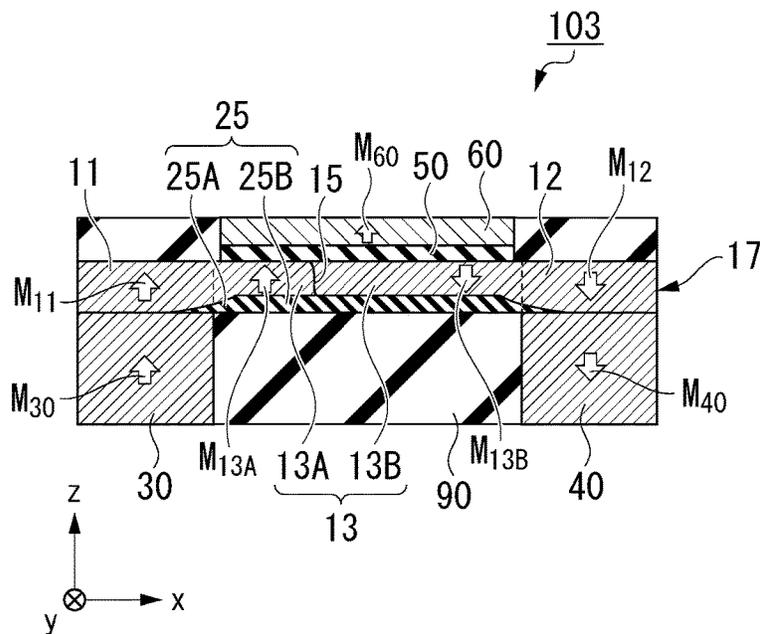


FIG. 11

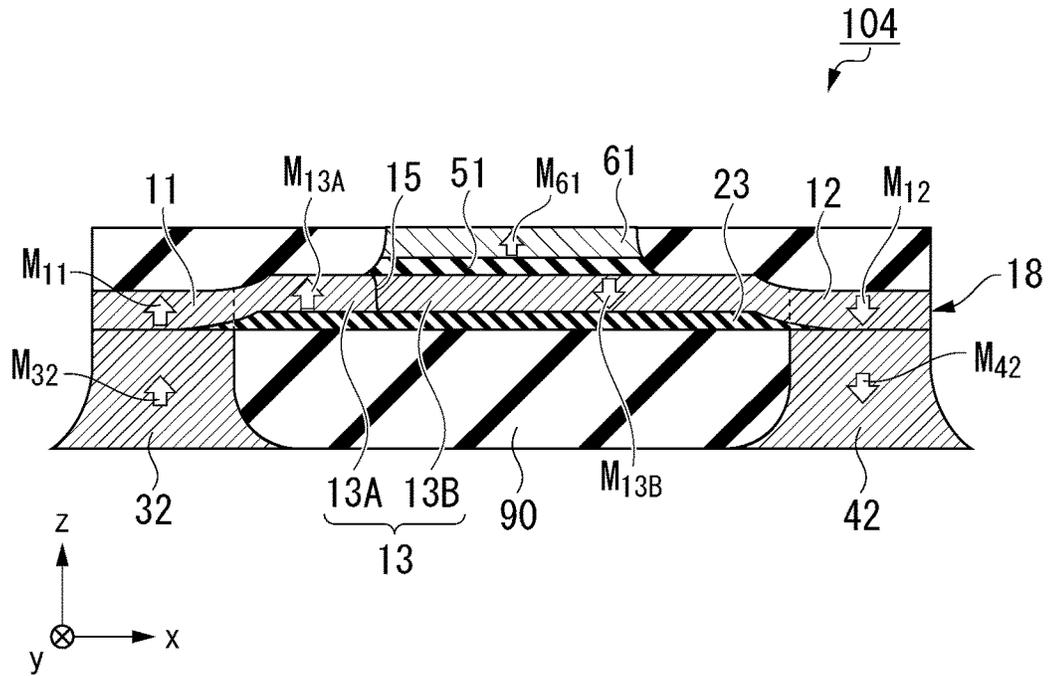


FIG. 12

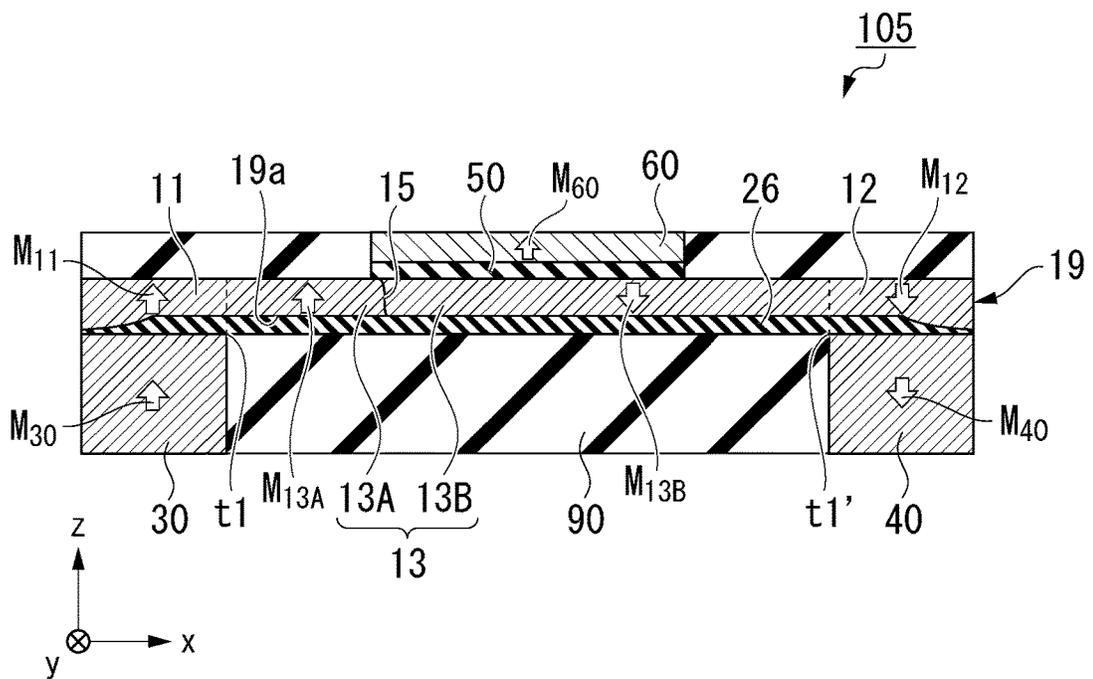
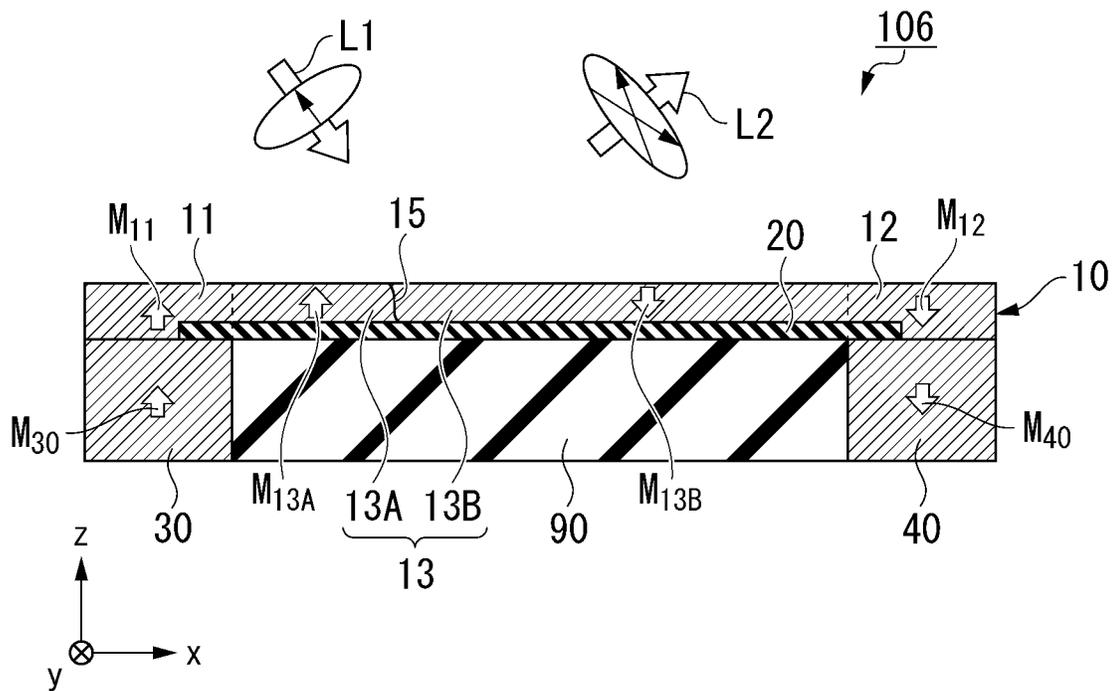


FIG. 13



MAGNETIC DOMAIN WALL MOVEMENT ELEMENT AND MAGNETIC RECORDING ARRAY

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a magnetic domain wall movement element and a magnetic recording array. Priority is claimed on Japanese Patent Application No. 2019-181361, filed on Oct. 1, 2019, the contents of which are incorporated herein by reference.

Description of Related Art

Attention has been focused on next-generation non-volatile memories that will replace flash memories or the like for which the limit of miniaturization has been reached. For example, magnetoresistive random access memories (MRAMs), resistance random access memories (ReRAMs), phase change random access memories (PCRAMs), and the like are known as next-generation non-volatile memories.

In MRAMs, a change in resistance value caused due to change in magnetization direction is used for data recording. Data recording is carried out by each of the variable magnetoresistance elements constituting the MRAM. For example, Patent Document 1 describes a variable magnetoresistance elements (magnetic domain wall movement element) which can record multi-valued data by moving a magnetic domain wall in a magnetic recording layer. Patent Document 1 describes that an intermediate layer is provided between a magnetic coupling layer and a first magnetization fixing region. Further, it describes that the intermediate layer may be formed so as to be in contact with the entire magnetic recording layer, and the intermediate layer may be used as the base layer.

PATENT DOCUMENT

[Patent Document 1] PCT International Publication No. WO2009/019949

SUMMARY OF THE INVENTION

Since a magnetic domain wall movement element records data in a multi-valued or analog manner according to a position of the magnetic domain wall, it is necessary to maintain the magnetic domain wall in the magnetic recording layer. The magnetic domain wall is formed by twisting the direction of magnetization in the magnetic recording layer. For example, when ferromagnetic layers oriented in different directions are brought close to different positions of a magnetic recording layer to create different magnetic domains in the magnetic recording layer, the direction of magnetization is twisted in the magnetic recording layer and a magnetic domain wall is generated. If each magnetic domain is not sufficiently fixed, the moving range of the magnetic domain wall becomes wider than the desired range, and in some cases, the magnetic domain wall disappears. For example, the variable magnetoresistance elements shown in Patent Document 1 fixes the magnetization in the first magnetization fixed region by magnetic coupling. However, the magnetic coupling between the magnetic coupling layer and the first magnetization fixing region may not be sufficiently obtained, and the magnetic domain may be insufficiently fixed.

The present invention was made in view of the above-described problems and provides a magnetic domain wall movement element and a magnetic memory in which the movement of the magnetic domain wall is stable.

(1) A magnetic domain wall movement element according to a first aspect includes: a wiring layer containing a ferromagnetic material; a non-magnetic layer in contact with the first surface of the wiring layer; a first conductive layer connected to the first surface of the wiring layer and containing a ferromagnetic material; and a second conductive layer connected to the wiring layer at a distance from the first conductive layer, wherein a first part of the connection face of the first conductive layer is directly connected to the wiring layer, and a second part of the connection face other than the first part is connected to the wiring layer via the non-magnetic layer.

(2) In the magnetic domain wall movement element according to a second aspect includes: a wiring layer containing a ferromagnetic material; a non-magnetic layer in contact with the first surface of the wiring layer; a first conductive layer connected to the first surface of the wiring layer and containing a ferromagnetic material; and a second conductive layer connected to the wiring layer at a distance from the first conductive layer, wherein the first conductive layer is connected to the wiring layer via the non-magnetic layer; the thickness of the non-magnetic layer at a position located between the first conductive layer and the wiring layer is thinner than the thickness of the non-magnetic layer at a position which overlaps the first end of the connection face of the first conductive layer on the side near the second conductive layer in plan view.

(3) In the magnetic domain wall movement element according to the aspect, the area of the first part is wider than the area of the second part.

(4) In the magnetic domain wall movement element according to the aspect, the connection face of the first conductive layer is recessed in the lamination direction, and a part of the non-magnetic layer is fitted in the recess of the connection face.

(5) In the magnetic domain wall movement element according to the aspect, the first surface of the wiring layer is recessed in the lamination direction, and the non-magnetic layer is fitted in the recess of the connection face.

(6) In the magnetic domain wall movement element according to the aspect, the non-magnetic layer located between the first conductive layer and the wiring layer becomes thinner as it moves away from the first end of the connection face on the side near the second conductive layer.

(7) In the magnetic domain wall movement element according to the aspect, the average thickness of the non-magnetic layer between the first conductive layer and the wiring layer is 10 Å or less.

(8) In the magnetic domain wall movement element according to the aspect, the second conductive layer contains a ferromagnetic material and a first part of the connection face of the second conductive layer is directly connected to the wiring layer, and a second part of the connection face other than the first part is connected to the wiring layer via the non-magnetic layer.

(9) In the magnetic domain wall movement element according to the aspect, the second conductive layer contains a ferromagnetic material and the thickness of the non-magnetic layer at a position located between the second conductive layer and the wiring layer is thinner than the thickness of the non-magnetic layer at a position which

overlaps the first end of the connection face of the second conductive layer on the side near the first conductive layer in plan view.

(10) The magnetic domain wall movement element according to the aspect, further includes: a ferromagnetic layer located above the second surface of the wiring layer opposite the first surface; and a second non-magnetic layer located between the ferromagnetic layer and the wiring layer.

(11) In the magnetic domain wall movement element according to the aspect, the non-magnetic layer has a thickness changing portion that becomes thinner as the distance from the ferromagnetic layer increases and the thickness changing portion does not overlap the ferromagnetic layer when viewed from the lamination direction.

(12) In the magnetic domain wall movement element according to the aspect, the non-magnetic layer has a thickness changing portion that becomes thinner as the distance from the ferromagnetic layer increases and a part of the thickness changing portion overlaps the ferromagnetic layer when viewed from the lamination direction.

(13) A magnetic recording array according to a third aspect may include: a plurality of the magnetic domain wall movement elements according to the aspect.

According to the magnetic domain wall movement element and the magnetic recording array according to the aspect, it is possible to stabilize the movement of the magnetic domain wall.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a constitution diagram of a magnetic recording array according to a first embodiment.

FIG. 2 is a cross-sectional view of a main part of the magnetic recording array according to the first embodiment.

FIG. 3 is a cross-sectional view of a magnetic domain wall movement element according to the first embodiment.

FIG. 4 is a plan view of the magnetic domain wall movement element according to the first embodiment.

FIG. 5 is a cross-sectional view of a magnetic domain wall movement element according to a first comparative example.

FIG. 6 is a cross-sectional view of a magnetic domain wall movement element according to a second comparative example.

FIG. 7 is a cross-sectional view of a magnetic domain wall movement element according to a first modified example.

FIG. 8 is a cross-sectional view of a magnetic domain wall movement element according to a second modified example.

FIG. 9 is a cross-sectional view of a magnetic domain wall movement element according to another example of the second modified example.

FIG. 10 is a cross-sectional view of a magnetic domain wall movement element according to a third modified example.

FIG. 11 is a cross-sectional view of a magnetic domain wall movement element according to a fourth modified example.

FIG. 12 is a cross-sectional view of a magnetic recording array according to a second embodiment.

FIG. 13 is a cross-sectional view of a magnetic recording array according to a third embodiment.

DETAILED DESCRIPTION OF THE INVENTION

This embodiment will be described in detail below with reference to the drawings as appropriate. In the drawings

used in the following description, in order to make the characteristics of the present invention easy to understand, for convenience, characteristic portions may be illustrated in an enlarged manner in some cases and dimensional ratios or the like of constituent elements may be different from actual dimensional ratios in some cases. The materials, dimensions, and the like exemplified in the following description are merely examples and the present invention is not limited thereto and it is possible to appropriately change and implement the present invention with a range in which the effects of the present invention can be obtained.

First, directions will be defined. An x direction and a y direction are directions substantially parallel to one surface of a substrate Sub (see FIG. 2) which will be described later. The x direction is a direction in which a wiring layer 10 which will be described later extends, and is also a direction from the first conductive layer 30 to the second conductive layer 40, which will be described later. The y direction is a direction orthogonal to the x direction. A z direction is a direction from the substrate Sub to the magnetic domain wall movement element 100, which will be described later. The z direction is an example of a lamination direction. Furthermore, the expression "extends in the x direction" in the specification means that, for example, a dimension in the x direction is larger than a minimum dimension among dimensions in the x direction, the y direction, and the z direction. The same applies to the case of extending in other directions.

First Embodiment

FIG. 1 is a constitution diagram of a magnetic recording array according to a first embodiment. The magnetic recording array 200 includes a plurality of first wirings Wp1 to Wp3, a plurality of second wirings Cm1 to Cm3, a plurality of third wirings Rp1 to Rp3, a plurality of first switching elements 110, a plurality of second switching elements 120, and a plurality of third switching elements 130. The magnetic recording array 200 can be used, for example, in a magnetic memory, a product-sum calculator, and a neuro-morphic device.

<First Wiring, Second Wiring, Third Wiring>

The first wirings Wp1 to Wpn are write wirings. The first wirings Wp1 to Wpn electrically connect the power supply and one or more magnetic domain wall movement elements 100. The power supply is connected to one end of the magnetic recording array 200 during use.

The second wirings Cm1 to Cmn are common wirings. Each of the common wirings is a wiring used both at the time of writing data and at the time of reading data. The second wirings Cm1 to Cmn electrically connect a reference potential and one or more magnetic domain wall movement elements 100. The reference potential is, for example, ground. The second wirings Cm1 to Cmn may be provided in each of the plurality of magnetic domain wall movement elements 100 or may be provided over the plurality of magnetic domain wall movement elements 100.

The third wirings Rp1 to Rpn are read wirings. The third wirings Rp1 to Rpn electrically connect a power supply and one or more magnetic domain wall movement elements 100. The power supply is connected to one end of the magnetic recording array 200 during use.

<First Switching Element, Second Switching Element, and Third Switching Element>

The first switching element 110, the second switching element 120, and the third switching element 130 shown in FIG. 1 are connected to each of the plurality of magnetic

domain wall movement elements **100**. A device in which switching elements are connected to the magnetic domain wall movement elements **100** is called a semiconductor device. The first switching element **110** is connected between each of the magnetic domain wall movement elements **100** and the each of first wirings Wp1 to Wpn. The second switching element **120** is connected between each of the magnetic domain wall movement elements **100** and each of the second wirings Cm1 to Cmn. The third switching element **130** is connected between each of the magnetic domain wall movement elements **100** and each of the third wirings Rp1 to Rpn.

If the first switching element **110** and the second switching elements **120** are turned on, a write current flows between the first wirings Wp1 to Wpn and the second wirings Cm1 to Cmn connected to predetermined magnetic domain wall movement elements **100**. If the first switching elements **110** and the third switching elements **130** are turned on, a read current flows between the first wirings Wp1 to Wpn and the third wirings Rp1 to Rpn connected to predetermined magnetic domain wall movement elements **100**.

The first switching elements **110**, the second switching elements **120**, and the third switching elements **130** are elements configured to control a flow of a current. For example, as the first switching elements **110**, the second switching elements **120**, and the third switching elements **130**, elements such as transistors and ovonic threshold switches (OTSs) in which a phase change of a crystal layer is used, elements such as a metal-insulator transition (MIT) switch in which a change in band structure is used, elements such as Zener diodes and avalanche diodes in which a breakdown voltage is used, elements in which conductivity changes with a change in atomic position, and the like can be utilized.

Any one of the first switching element **110**, the second switching element **120**, and the third switching element **130** may be shared by the magnetic domain wall movement elements **100** connected to the same wiring. For example, when the first switching element **110** is shared, one first switching element **110** is provided upstream of the first wirings Wp1 to Wpn. For example, when the second switching element **120** is shared, one second switching element **120** is provided upstream of the second wirings Cm1 to Cmn. For example, when the third switching element **130** is shared, one third switching element **130** is provided upstream of the third wirings Rp1 to Rpn.

FIG. 2 is a cross-sectional view of a main part of the magnetic recording array according to the first embodiment. FIG. 2 is a cross section of one magnetic domain wall movement element **100** in FIG. 1 cut in an xz plane passing through the center of the width of the wiring layer **10** in the y direction.

The first switching element **110** and the second switching element **120** shown in FIG. 2 are transistors Tr. The transistor Tr has a gate electrode G, a gate insulating film GI, and a source region S and a drain region D formed on a substrate Sub. The substrate Sub is, for example, a semiconductor substrate. The third switching element **130** is electrically connected to the electrode E and is located, for example, in the depth direction (-y direction) of the paper surface.

Each of the transistors Tr and the magnetic domain wall movement element **100** are electrically connected to each other via the connection wiring Cw. The connection wiring Cw contains a material having conductivity. The connection wiring Cw extends, for example, in the z direction. The

connection wiring Cw is, for example, a via wiring formed in the opening of the insulating layer **90**.

The magnetic domain wall movement element **100** and the transistor Tr are electrically separated by an insulating layer **90** except for the connection wiring Cw. The insulating layer **90** is an insulating layer that insulates between the wirings of the multilayer wiring and between the elements. The insulating layer **90** is made of, for example, silicon oxide (SiO_x), silicon nitride (SiN_x), silicon carbide (SiC), chromium nitride, silicon carbonitride (SiCN), silicon oxynitride (SiON), aluminum oxide (Al₂O₃), zirconium oxide (ZrO_x), and the like.

<Magnetic Domain Wall Movement Element>

FIG. 3 is a cross-sectional view of the magnetic domain wall movement element **100** cut in an xz plane passing through the center of the width of the wiring layer **10** in the y direction. The magnetic domain wall movement element **100** includes a wiring layer **10**, a non-magnetic layer **20**, a first conductive layer **30**, a second conductive layer **40**, a second non-magnetic layer **50**, and a ferromagnetic layer **60**. When writing data to the magnetic domain wall movement element **100**, a write current is passed through the wiring layer **10** between the first conductive layer **30** and the second conductive layer **40**. When reading data from magnetic domain wall movement element **100**, a read current is passed between the first conductive layer **30** or the second conductive layer **40** and the ferromagnetic layer **60**.

<Wiring Layer>

The wiring layer **10** is a portion extending in the x direction and is a portion to which a write current is applied. The wiring layer **10** is, for example, a rectangle having a long axis in the x direction and a short axis in the y direction in a plan view from the z direction. The wiring layer **10** is connected to the first conductive layer **30** and the second conductive layer **40**. Hereinafter, the surface of the wiring layer **10** on the side to which the first conductive layer **30** is connected is referred to as a first surface **10a**. The write current flows along the wiring layer **10** from the first conductive layer **30** toward the second conductive layer **40**, or from the second conductive layer **40** toward the first conductive layer **30**. The wiring layer **10** is laminated on the non-magnetic layer **20**, the first conductive layer **30**, and the second conductive layer **40**.

The wiring layer **10** is a layer capable of magnetically recording information by changing the internal magnetic state. The wiring layer **10** may be called a magnetic recording layer or a magnetic domain wall movement layer.

The wiring layer **10** includes fixed magnetization regions **11**, **12** and a magnetic domain wall movement region **13**. The magnetic domain wall movement region **13** is sandwiched between two fixed magnetization regions **11** and **12**.

The fixed magnetization region **11** is a region in which the wiring layer **10** overlaps with the connection face **30a** of the first conductive layer **30** when viewed from the z direction. The fixed magnetization region **12** is a region in which the wiring layer **10** overlaps with the connection face **40a** of the second conductive layer **40** when viewed from the z direction. The magnetizations M11 and M12 in the fixed magnetization regions **11** and **12** are harder to be reversed than the magnetizations M13A and M13B in the magnetic domain wall movement region **13**, and are not reversed even if an external force with a threshold value for reversing the magnetizations M13A and M13B is applied to the magnetizations M11 and M12. Therefore, it is said that that the magnetizations M11 and M12 of the magnetization fixing regions **11** and **12** are fixed to the magnetizations M13A and M13B of the magnetic domain wall movement region **13**.

The magnetization M11 in the fixed magnetization region 11 and the magnetization M12 in the fixed magnetization region 12 are oriented in different directions. The magnetization M11 in the fixed magnetization region 11 and the magnetization M12 in the fixed magnetization region 12 are oriented, for example, in opposite directions. The magnetization M11 in the fixed magnetization region 11 is oriented, for example, in the +z direction and the magnetization M12 in the fixed magnetization region 12 is oriented, for example, in the -z direction.

The magnetic domain wall movement region 13 is composed of a first magnetic domain 13A and a second magnetic domain 13B. The first magnetic domain 13A is adjacent to the fixed magnetization region 11. The magnetization M13A of the first magnetic domain 13A is influenced by the magnetization M11 of the fixed magnetization region 11, and is oriented, for example, in the same direction as the magnetization M11 of the fixed magnetization region 11. The second magnetic domain 13B is adjacent to the fixed magnetization region 12. The magnetization M13B of the second magnetic domain 13B is influenced by the magnetization M12 of the fixed magnetization region 12, and is oriented, for example, in the same direction as the magnetization M12 of the fixed magnetization region. Therefore, the magnetization M13A of the first magnetic domain 13A and the magnetization M13B of the second magnetic domain 13B are oriented in different directions. The magnetization M13A of the first magnetic domain 13A and the magnetization M13B of the second magnetic domain 13B are oriented, for example, in opposite directions.

The boundary between the first magnetic domain 13A and the second magnetic domain 13B is the magnetic domain wall 15. The magnetic domain wall 15 moves within the magnetic domain wall movement region 13. In principle, the magnetic domain wall 15 does not penetrate into the fixed magnetization regions 11 and 12.

When the ratio of the first magnetic domain 13A and the second magnetic domain 13B in the magnetic domain wall movement region 13 changes, the magnetic domain wall 15 moves. The magnetic domain wall 15 moves by passing a write current in the x direction of the magnetic domain wall movement region 13. For example, when a write current (for example, a current pulse) in the +x direction is applied to the magnetic domain wall movement region 13, electrons flow in the -x direction opposite to the current, so that the magnetic domain wall 15 moves in the -x direction. When a current flows from the first magnetic domain 13A to the second magnetic domain 13B, the spin-polarized electrons in the second magnetic domain 13B reverse the magnetization M13A of the first magnetic domain 13A. When the magnetization M13A in the first magnetic domain 13A is reversed, the magnetic domain wall 15 moves in the -x direction.

The wiring layer 10 is made of a magnetic material. It is desirable that the wiring layer 10 include at least one element selected from the group consisting of Co, Ni, Fe, Pt, Pd, Gd, Tb, Mn, Ge, and Ga. Examples of the material used for the magnetic recording layer 20 include a laminated film made of Co and Ni, a laminated film made of Co and Pt, a laminated film made of Co and Pd, a MnGa-based material, a GdCo-based material, and a TbCo-based material. Ferromagnetic materials such as a MnGa-based material, a GdCo-based material, and a TbCo-based material have a small saturation magnetization and a small threshold value current for moving a magnetic domain wall. Furthermore, a laminated film made of Co and Ni, a laminated film made of Co

and Pt, and a laminated film made of Co and Pd have a large coercivity and a slow moving speed of a magnetic domain wall.

<Non-Magnetic Layer>

The non-magnetic layer 20 is in contact with the first surface 10a of the wiring layer 10. The non-magnetic layer 20 is on the first surface 10a of the wiring layer 10. The non-magnetic layer 20 shown in FIG. 3 fits into the recess 10c formed on the first surface 10a. The non-magnetic layer 20 shown in FIG. 3 straddles a part of the fixed magnetization region 11, the magnetic domain wall movement 13, and a part of the fixed magnetization region 12.

The non-magnetic layer 20 extends from a position overlapping the magnetic domain wall movement 13 in the z direction toward between the fixed magnetization region 11 and the first conductive layer 30 and between the fixed magnetization region 12 and the second conductive layer 40. The first end of the non-magnetic layer 20 is between the fixed magnetization region 11 and the first conductive layer 30. The second end of the non-magnetic layer 20 is between the fixed magnetization region 12 and the second conductive layer 40.

The non-magnetic layer 20 is made of a non-magnetic material. The non-magnetic layer 20 defines, for example, the crystal structure of the wiring layer 10. The crystal structure of the non-magnetic layer 20 enhances the crystallinity of the wiring layer 10 and enhances the orientation of the magnetization of the wiring layer 10. The crystal structure of the non-magnetic layer 20 is, for example, amorphous, (001) oriented NaCl structure, (002) oriented perovskite structure represented by the composition formula of ABO_3 , or (001) oriented tetragonal structure or cubic structure.

The non-magnetic layer 20 is a conductor or an insulator. The non-magnetic layer 20 is preferably a conductor. When the non-magnetic layer 20 is a conductor, the thickness of the non-magnetic layer 20 is preferably thinner than the thickness of the wiring layer 10. The non-magnetic layer 20 contains, for example, Ta, Ru, Pt, Ir, Rh, W, Pd, Cu, Au, and Cu. The non-magnetic layer 20 is, for example, a Ta layer, a Pt layer, or a laminate of a Ta layer and a Pt layer.

The thickness of the non-magnetic layer 20 is, for example, substantially constant in the xy plane. The average thickness of the non-magnetic layer 20 is, for example, 50 Å or less. The average thickness is the average value of the thicknesses of the non-magnetic layers 20 measured at the positions in the x directions of dividing the non-magnetic layer 20 into 10 at equal intervals in the x direction.

<First Conductive Layer and Second Conductive Layer>

The first conductive layer 30 is connected to the first surface 10a of the wiring layer 10. The second conductive layer 40 is connected to, for example, the first surface 10a of the wiring layer 10. The second conductive layer 40 may be connected to a surface other than the first surface 10a of the wiring layer 10. The second conductive layer 40 is separated from the first conductive layer 30 and is connected to the wiring layer 10. The first conductive layer 30 is connected to, for example, the first end of the wiring layer 10, and the second conductive layer 40 is connected to, for example, the second end of the wiring layer 10. The first conductive layer 30 and the second conductive layer 40 are, for example, connecting portions between the connecting wiring Cw and the wiring layer 10.

The first conductive layer 30 contains a magnetic material. The magnetization M30 of the first conductive layer 30 is oriented in one direction. The magnetization M30 is oriented, for example, in the +z direction. The first conduc-

tive layer **30** fixes the magnetization **M11** in the fixed magnetization region **11**. The magnetization **M30** of the first conductive layer **30** and the magnetization **M11** of the fixed magnetization region **11** are oriented, for example, in the same direction.

The first conductive layer **30** contains, for example, a metal selected from the group consisting of Cr, Mn, Co, Fe and Ni, or an alloy containing at least one of these metals, or an alloy containing at least one of these metals and at least one of B, C, and N. The first conductive layer **30** is made of, for example, Co—Fe, Co—Fe—B, Ni—Fe, or the like. When an easy magnetization axis of the first conductive layer **30** is in the z direction (perpendicular magnetization film), the first conductive layer **30** is preferably a laminate of a ferromagnetic material selected from the group consisting of Co, Fe and Ni and a non-magnetic material selected from the group consisting of Pt, Pd, Ru and Rh. Further, the first conductive layer **30** may have a synthetic antiferromagnetic structure (an SAF structure). The synthetic antiferromagnetic structure is composed of two magnetic layers having a non-magnetic layer disposed therebetween. Magnetization of each of the two magnetic layers is fixed, and directions of the fixed magnetization are opposite.

The second conductive layer **40** is made of a conductive material. The second conductive layer **40** contains a magnetic material. When the second conductive layer **40** contains a magnetic material, the magnetization **M40** of the second conductive layer **40** is oriented in a direction different from the magnetization **M30** of the first conductive layer **30**. The magnetization **M40** is oriented, for example, in the $-z$ direction. In this case, the second conductive layer **40** fixes the magnetization **M12** in the fixed magnetization region **12**, and the magnetization **M40** in the second conductive layer **40** and the magnetization **M12** in the fixed magnetization region **12** are oriented, for example, in the same direction. The second conductive layer **40** may be made of, for example, the same material as the first conductive layer **30**. When the second conductive layer **40** does not contain a magnetic material, the magnetization **M12** in the fixed magnetization region **12** is fixed by, for example, an external magnetic field.

A part of the first conductive layer **30** is in direct contact with the wiring layer **10**, and a part of the first conductive layer **30** is in contact with the wiring layer **10** via the non-magnetic layer **20**. The connection face (surface) **30a** of the first conductive layer **30** is partially in contact with the wiring layer **10** and partly in contact with the non-magnetic layer **20**. Hereinafter, a part of the connection face **30a** that is in direct contact with the wiring layer **10** is referred to as a first part **30a1**, and a part of the connection face **30a** that is in contact with the wiring layer **10** via the non-magnetic layer **20** is referred to as a second part **30a2**. As shown in FIG. 4, for example, the area of the first part **30a1** is larger than the area of the second part **30a2**. FIG. 4 is a plan view of the magnetic domain wall movement element according to the first embodiment.

A part of the second conductive layer **40** shown in FIGS. 3 and 4 is in direct contact with the wiring layer **10**, and a part of the second conductive layer **40** is in contact with the wiring layer **10** via the non-magnetic layer **20**. The connection face (surface) **40a** of the second conductive layer **40** is partially in contact with the wiring layer **10** and partly in contact with the non-magnetic layer **20**. Hereinafter, a part of the connection face **40a** that is in direct contact with the wiring layer **10** is referred to as a first part **40a 1**, and a part of the connection face **40a** that is in contact with the wiring layer **10** via the non-magnetic layer **20** is referred to as a

second part **40a 2**. As shown in FIG. 4, for example, the area of the first part **40a 1** is larger than the area of the second part **40a 2**.

<Second Non-Magnetic Layer>

The second non-magnetic layer **50** is located between the wiring layer **10** and the ferromagnetic layer **60**. The second non-magnetic layer **50** is laminated on the second surface of the wiring layer **10**. The second surface is a surface facing the first surface **10a**.

The second non-magnetic layer **50** is made of, for example, a non-magnetic insulator, a semiconductor or a metal. The non-magnetic insulator is, for example, Al_2O_3 , SiO_2 , MgO , $MgAl_2O_4$, and a material in which Al, Si, and Mg are partly replaced with Zn, Be, and the like. These materials have a large bandgap and are excellent in insulating properties. When the second non-magnetic layer **50** is made of a non-magnetic insulator, the second non-magnetic layer **50** is a tunnel barrier layer. The non-magnetic metal is, for example, Cu, Au, Ag or the like. Non-magnetic semiconductors are, for example, Si, Ge, $CuInSe_2$, $CuGaSe_2$, Cu (In, Ga) Se_e and the like.

The thickness of the second non-magnetic layer **50** is preferably 20 Å or more, and more preferably 30 Å or more. When the thickness of the second non-magnetic layer **50** is large, the resistance area product (RA) of the magnetic domain wall movement element **100** becomes large. The resistance area product (RA) of the magnetic domain wall movement element **100** is preferably $1 \times 10^4 \Omega \mu m^2$ or more, and more preferably $1 \times 10^5 \Omega \mu m^2$ or more. The resistance area product (RA) of the magnetic domain wall movement element **100** is represented by the product of the element resistance of one magnetic domain wall movement element **100** and the element cross-sectional area of the magnetic domain wall movement element **100** (the area of the cut surface obtained by cutting the second non-magnetic layer **50** in the xy plane).

The ferromagnetic layer **60** is on the second non-magnetic layer **50**. The ferromagnetic layer **60** has a unidirectionally oriented magnetization **M60**. The magnetization **M60** of the ferromagnetic layer **60** is less likely to be reversed than the magnetizations **M13A** and **M13B** of the magnetic domain wall movement region **13** when a predetermined external force is applied. The predetermined external force is, for example, an external force applied to the magnetization by an external magnetic field or an external force applied to the magnetization by a spin polarization current. The ferromagnetic layer **60** is sometimes called a fixed magnetization layer or a magnetization reference layer.

The resistance value of the magnetic domain wall movement element **100** changes depending on a difference in relative angle between the magnetization of the ferromagnetic layer **60** and the magnetizations **M13A** and **M13B** of the magnetic domain wall movement region **13**. The magnetization **M13A** of the first magnetic domain **13A** is, for example, in the same direction (parallel) as the magnetization **M60** of the ferromagnetic layer **60**, and the magnetization **M13B** of the second magnetic domain **13B** is, for example, in the opposite direction (antiparallel) to the magnetization **M60** of the ferromagnetic layer **60**. When the area of the first magnetic domain **13A** overlapping with the ferromagnetic layer **60** in plan view from the z direction becomes large, the resistance value of the magnetic domain wall movement element **100** becomes low. On the contrary, when the area of the second magnetic domain **13B** overlapping with the ferromagnetic layer **60** in plan view from the z direction becomes large, the resistance value of the magnetic domain wall movement **100** becomes high.

The ferromagnetic layer **60** includes a ferromagnetic material. The ferromagnetic layer **60** includes, for example, a material that easily obtains a coherent tunnel effect with the wiring layer **10**. The ferromagnetic layer **60** includes, for example, a metal selected from the group consisting of Cr, Mn, Co, Fe, and Ni, an alloy containing at least one metal of these metals, an alloy containing at least one of these metals and at least one of B, C, and N or the like. The ferromagnetic layer **60** is made of, for example, Co—Fe, Co—Fe—B, or Ni—Fe.

The ferromagnetic layer **60** may be a, for example, Heusler alloy. The Heusler alloy is a half-metal and has a high spin polarization. The Heusler alloy is an intermetallic compound having a chemical composition of XYZ or X₂YZ. X represents a Co-, Fe-, Ni-, or Cu-group transition metal element or a noble metal element in the periodic table, Y represents a Mn-, V-, Cr-, or Ti-group transition metal or an element of the X type in the periodic table, and Z represents a typical element from Group III to Group V. Examples of the Heusler alloy include Co₂FeSi, Co₂FeGe, Co₂FeGa, Co₂MnSi, Co₂Mn_{1-a}Fe_aAl_bSi_{1-b}, Co₂FeGe_{1-c}Ga_c, and the like.

A film thickness of the ferromagnetic layer **60** is preferably 1.5 nm or less, and is more preferably 1.0 nm or less when an easy magnetization axis of the ferromagnetic layer **60** is assumed to a z direction (a perpendicular magnetization film is assumed). If the film thickness of the ferromagnetic layer **60** is reduced, perpendicular magnetic anisotropy (interface perpendicular magnetic anisotropy) can be added to the ferromagnetic layer **60** at an interface between the ferromagnetic layer **60** and another layer (the second non-magnetic layer **50**), and the magnetization of the ferromagnetic layer **60** is easily oriented in the z direction.

When an easy magnetization axis of the ferromagnetic layer **60** is in the z direction, it is preferable that the ferromagnetic layer **60** be a laminate of a ferromagnetic material selected from the group consisting of Co, Fe, and Ni and a non-magnetic material selected from the group consisting of Pt, Pd, Ru, and Rh, and it is more preferable to insert a non-magnetic material selected from the group consisting of Ir and Ru as an intermediate layer at any position in the laminate. If a ferromagnetic material and a non-magnetic material are laminated, it is possible to add perpendicular magnetic anisotropy and when the intermediate layer is inserted, it is possible to more strongly fix the magnetization of the ferromagnetic layer **60** in z direction.

An antiferromagnetic layer may be provided on the surface of the ferromagnetic layer **60** opposite to the second non-magnetic layer **50** via a spacer layer. The ferromagnetic layer **60**, the spacer layer, and the antiferromagnetic layer have a synthetic antiferromagnetic structure (a SAF structure). The synthetic antiferromagnetic structure consists of two magnetic layers sandwiching a non-magnetic layer. The antiferromagnetic coupling between the ferromagnetic layer **60** and the antiferromagnetic layer increases the coercive force of the ferromagnetic layer **60** as compared with the case where the antiferromagnetic layer is not provided. The antiferromagnetic layer is, for example, IrMn, PtMn, or the like. The spacer layer contains, for example, at least one selected from the group consisting of Ru, Ir, and Rh.

The direction of magnetization of each layer of the magnetic domain wall movement element **100** can be confirmed, for example, by measuring the magnetization curve. The magnetization curve can be measured using, for example, MOKE (Magneto Optical Kerr Effect). The measurement by MOKE is a measurement method performed by making linearly polarized light incident on an object to be

measured and using a magneto-optical effect (magnetic Kerr effect) in which rotation in the polarization direction and the like occurs.

Next, a method of manufacturing the magnetic recording array **200** will be described. The magnetic recording array **200** is manufactured by a laminating step of each layer and a processing step of processing a part of each layer into a predetermined shape. For the lamination of each layer, a sputtering method, a chemical vapor deposition (CVD) method, an electron beam vapor deposition method (an EB vapor deposition method), an atomic laser deposition method, or the like can be used. The processing of each layer can be performed by using photolithography or the like.

First, impurities are doped at a predetermined position on the substrate Sub to form a source region S and a drain region D. Next, a gate insulating film GI and a gate electrode G are formed between the source region S and the drain region D. The source region S, drain region D, gate insulating film GI, and gate electrode G serve as transistors Tr.

Next, the insulating layer **90** is formed so as to cover the transistor Tr. Further, the connection wiring Cw is formed by forming an opening in the insulating layer **90** and filling the opening with a conductor. The first wiring Wp and the second wiring Cm are formed by laminating the insulating layer **90** to a predetermined thickness, forming a groove in the insulating layer **90**, and filling the groove with a conductor.

The first conductive layer **30** and the second conductive layer **40** can be formed, for example, by laminating a ferromagnetic layer, a non-magnetic layer, and a ferromagnetic layer in this order on one surface of the insulating layer **90** and the connection wiring Cw, and by removing a portion other than the portion that becomes the first conductive layer **30** and the conductive layer **40**. The removed portion is filled with, for example, an insulating layer **90**.

Next, the non-magnetic layer **20** is laminated on the first conductive layer **30**, the second conductive layer **40**, and the insulating layer **90**. A resist is formed on a part of the non-magnetic layer **20**. The resist is formed so as to straddle a part of the fixed magnetization region **11**, the magnetic domain wall movement region **13**, and the fixed magnetization region **12**. Next, the non-magnetic layer **20** and the resist are irradiated with an ion beam. The portion of the non-magnetic layer **20** that is not coated with the resist is removed.

Next, the wiring layer **10**, the second non-magnetic layer **50**, and the ferromagnetic layer **60** are laminated in this order. After that, the second non-magnetic layer **50** and the ferromagnetic layer **60** are processed into a predetermined shape to obtain the magnetic domain wall movement element **100** shown in FIGS. **3** and **4**.

According to the magnetic domain wall movement element **100** according to the first embodiment, the operation of the magnetic domain wall **15** in the wiring layer **10** can be stabilized. The operation of the magnetic domain wall **15** is, for example, the operating range of the magnetic domain wall **15**, and is, for example, the ease of movement of the magnetic domain wall **15**. When the controllability of the domain wall **15** is improved, malfunctions such as erroneous writing can be prevented, and the reliability of the magnetic domain wall movement element **100** is improved.

FIG. **5** is a cross-sectional view of the magnetic domain wall movement element **111** according to the first comparative example cut in the xz plane passing through the center of the wiring layer **16** in y direction. The magnetic domain wall movement element **111** differs from the magnetic

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domain wall movement element **100** in that the first surface **16a** of the wiring layer **16** is flat and the non-magnetic layer **21** is on the entire surface of the first surface **16a** of the wiring layer **16**. The wiring layer **16** corresponds to the wiring layer **10** described above, and the non-magnetic layer **21** corresponds to the non-magnetic layer **20** described above. The same components as those of the magnetic domain wall movement element **100** in the magnetic domain wall movement element **111** are designated by the same reference numerals, and the description thereof will be omitted.

In the magnetic domain wall movement element **111**, there is a non-magnetic layer **21** between the fixed magnetization region **11** and the first conductive layer **30**. That is, the magnetization **M11** of the fixed magnetization region **11** is fixed by magnetic coupling with the magnetization **M30** of the first conductive layer **30**. The magnetic coupling via the non-magnetic layer **21** is weaker than the magnetic coupling when the fixed magnetization region **11** and the first conductive layer **30** are in direct contact with each other. Therefore, when an unexpected overcurrent flows between the first conductive layer **30** and the second conductive layer **40**, or an unexpected heat is applied to the magnetic domain wall movement element **111**, the magnetization **M11** of the fixed magnetization region **11** may become reversed. When the magnetization **M11** in the fixed magnetization region **11** is reversed, the magnetic domain wall **15** invades the fixed magnetization regions **11** and **12**. In some cases, the magnetic domain wall **15** disappears. The invasion of the magnetic domain wall **15** into the fixed magnetization regions **11** and **12** and the disappearance of the magnetic domain wall **15** cause malfunctions such as erroneous writing, not the planned operation of the magnetic domain wall movement element **111**.

On the other hand, in the magnetic domain wall movement element **100** according to the first embodiment, the first conductive layer **30** and the wiring layer **10**, and the second conductive layer **40** and the wiring layer **10** are in direct contact with each other in the first portions **30a1** and **40a1**. Therefore, the magnetization **M11** in the fixed magnetization region **11** has a strong magnetic bond with the magnetization **M30** of the first conductive layer **30**, and the magnetization **M11** is strongly fixed. That is, the invasion of the magnetic domain wall **15** into the fixed magnetization regions **11** and **12** and the disappearance of the domain wall **15** are suppressed, and the operation of the magnetic domain wall movement element **100** is stabilized.

Further, when the area of the first portions **30a1** and **40a1** is larger than the area of the second portions **30a2** and **40a2**, the fixation of the magnetization of the fixed magnetization regions **11** and **12** becomes stronger. As a result, even when heat or the like is applied, it is possible to prevent the magnetic domain wall **15** from invading the fixed magnetization regions **11** and **12** and the magnetic domain wall **15** from disappearing.

Further, FIG. 6 is a cross-sectional view of the magnetic domain wall movement element **112** according to the second comparative example cut in the xz plane passing through the center of the wiring layer **10** in the y direction. The magnetic domain wall movement element **112** differs from the magnetic domain wall movement element **100** in that the non-magnetic layer **22** is located only at a position where the non-magnetic layer **22** overlaps the magnetic domain wall movement region **13** of the wiring layer **10**. The same components as those of the magnetic domain wall movement element **100** in the magnetic domain wall movement

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element **111** are designated by the same reference numerals, and the description thereof will be omitted.

When the magnetic domain wall movement element **112** is manufactured, the wiring layer **10** is laminated on the first conductive layer **30**, the non-magnetic layer **22**, and the second conductive layer **40**. Since the non-magnetic layer **22**, the first conductive layer **30**, and the second conductive layer **40** are made of different materials, the connection surfaces **22a** of the non-magnetic layer **22** and the connection surfaces **30a** and **40a** of the first conductive layer **30** and the second conductive layer **40** are difficult to be continuous. Therefore, a step **st** is formed between the non-magnetic layer **22** and the first conductive layer **30** and between the non-magnetic layer **22** and the second conductive layer **40**. Since the magnetization is affected by the interface, the orientation direction of the magnetization is disturbed in the vicinity of the step **st**. In the portion where the orientation direction of the magnetization is disturbed, the operation of the domain wall **15** becomes unstable and is trapped.

The boundary between the fixed magnetization regions **11** and **12** and the magnetic domain wall movement region **13** is a portion where the magnetic environment by which the magnetic domain wall **15** is received is different and where the magnetic domain wall **15** is easily trapped. If there is a trap factor of the structural magnetic domain wall **15**, that is, a step **st**, in this portion, the magnetic domain wall **15** may be strongly trapped. If the magnetic domain wall **15** is strongly trapped, the magnetic domain wall **15** does not operate normally even if a current having a predetermined current density is applied to the wiring layer **10**.

On the other hand, in the magnetic domain wall movement element **100** according to the first embodiment, the non-magnetic layer **20** straddles a part of the fixed magnetization region **11**, the magnetic domain wall movement region **13**, and a part of the fixed magnetization region **12**. Therefore, the step **st** is not formed at the boundary between the fixed magnetization regions **11** and **12** and the magnetic domain wall movement region **13**. Therefore, the strong trapping of the magnetic domain wall **15** is suppressed, and the operation of the magnetic domain wall movement element **100** is stabilized.

Although an example of the magnetic recording array **200** and the magnetic domain wall movement element **100** according to the first embodiment have been described in detail, the magnetic recording array **200** and the magnetic domain wall movement element **100** according to the first embodiment can be transformed or changed within the scope of the gist of the present invention.

For example, in FIGS. 3 and 4, the second conductive layer **40** and the wiring layer **10** are partly in direct contact with each other and partly in contact with the wiring layer **10** via the non-magnetic layer **20**. The relationship between the second conductive layer **40** and the wiring layer **10** is not limited to this case, and the second conductive layer **40** and the wiring layer **10** may be in direct contact with each other on the entire surface, or the entire surface may be connected via the non-magnetic layer **20**.

First Modified Example

FIG. 7 is a cross-sectional view of the magnetic domain wall movement element **101** according to the first modified example on the yz plane. The shapes of the wiring layer **17** and the non-magnetic layer **23** of the magnetic domain wall movement element **101** are different from those of the magnetic domain wall movement element **100**. The wiring layer **17** corresponds to the wiring layer **10** described above,

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and the non-magnetic layer 23 corresponds to the non-magnetic layer 20 described above. The same components as those of the magnetic domain wall movement element 100 in the magnetic domain wall movement element 101 are designated by the same reference numerals, and the description thereof will be omitted.

The non-magnetic layer 23 is different from the non-magnetic layer 20 in that it has a thickness changing portion 23A. Other characteristic configurations are the same as those of the non-magnetic layer 20. The non-magnetic layer 23 has a thickness changing portion 23A in which the thickness gradually decreases and a main portion 23B in which the thickness is substantially constant. The thickness of the thickness changing portion 23A becomes thinner as the distance from the midpoint in the x direction of the non-magnetic layer 23 increases. The thickness of the thickness changing portion 23A becomes thinner, for example, as the distance from the ferromagnetic layer 60 increases.

The thickness changing portion 23A is located at a position that does not overlap with the ferromagnetic layer 60 when viewed from the z direction. The non-magnetic layer 23 becomes thinner, for example, between the first conductive layer 30 and the wiring layer 10, as it is separated from the first end t1 on the side of the connection surface 30a closer to the second conductive layer 40. Further, the non-magnetic layer 23 becomes thinner, for example, between the second conductive layer 40 and the wiring layer 10, as the distance from the first end t1' on the side of the connection surface 40a closer to the first conductive layer 30.

The orientation direction of the magnetization of the wiring layer 10 is strongly influenced by the shape of the interface with other layers. The magnetization of the wiring layer 17 on the thickness changing portion 23A is inclined, for example, from the z direction to the y direction. When the thickness of the thickness changing portion 23A is gradually reduced, the inclination angle of the magnetization of the wiring layer 17 on the thickness changing portion 23A gradually changes depending on the position in the x direction. By gradually changing the inclination angle of the magnetization, the initial motion of the magnetic domain wall 15 becomes easy, and the reversal current density required for reversing the magnetization of the wiring layer 10 can be reduced.

Further, the main portion 23B is at a position where it overlaps with the ferromagnetic layer 60 when viewed from the z direction, and the thickness changing portion 23A is at a position where it does not overlap with the ferromagnetic layer 60 when viewed from the z direction. If the main portion 23B is located at a position overlapping the ferromagnetic layer 60, the resistance change rate (MR ratio) of the magnetic domain wall movement element 100 increases. The MR ratio of the magnetic domain wall movement element 100 decreases when the magnetization of the wiring layer 17 at a position overlapping the ferromagnetic layer 60 is tilted from a predetermined direction (for example, the z direction). When the thickness of the main portion 23B is substantially constant, the interface between the main portion 23B and the wiring layer 17 is flattened, and it is possible to prevent the magnetization from tilting from a predetermined direction.

Further, also in the first modified example, the average thickness of the non-magnetic layer 20 between the first conductive layer 30 or the second conductive layer 40 and the wiring layer 17 is preferably 10 Å or less.

In the magnetic domain wall movement element 101 according to the first modified example, the first conductive

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layer 30 and the wiring layer 17 are partly in direct contact with each other and partly in contact with each other via the non-magnetic layer 23. Therefore, the magnetic domain wall movement element 101 according to the first modified example also has the same effect as the magnetic domain wall movement element 100.

Second Modified Example

FIG. 8 is a cross-sectional view of the magnetic domain wall movement element 102 according to the second modified example on the yz plane. The position of the non-magnetic layer 24, and the shapes of the wiring layer 16, the first conductive layer 31 and the second conductive layer 41 of the magnetic domain wall movement element 102 are different from those of the magnetic domain wall movement element 100. The wiring layer 16 corresponds to the above-mentioned wiring layer 10, the non-magnetic layer 24 corresponds to the above-mentioned non-magnetic layer 20, the first conductive layer 31 corresponds to the above-mentioned first conductive layer 30, and the second conductive layer 41 corresponds to the above-mentioned second conductive layer 40. The same components as those of the magnetic domain wall movement element 100 in the magnetic domain wall movement element 102 are designated by the same reference numerals, and the description thereof will be omitted.

The thickness of the wiring layer 16 is substantially constant in the x direction. The first surface 16a of the wiring layer 16 has no depression and is flat.

The non-magnetic layer 24 is in contact with the first surface 16a of the wiring layer 16. The non-magnetic layer 24 is on the first surface 16a of the wiring layer 16. The non-magnetic layer 24 straddles a part of the fixed magnetization region 11, the magnetic domain wall movement region 13, and a part of the fixed magnetization region 12. The first end of the non-magnetic layer 24 is located between the fixed magnetization region 11 and the first conductive layer 31. The second end of the non-magnetic layer 24 is located between the fixed magnetization region 12 and the second conductive layer 41.

A part of the first conductive layer 31 is in direct contact with the wiring layer 16, and a part of the first conductive layer 31 is in contact with the wiring layer 16 via the non-magnetic layer 24. The first part 31a1 of the connection surface 31a is in direct contact with the wiring layer 16, and the second part 31a2 is in contact with the wiring layer 16 via the non-magnetic layer 24. The second portion 31a2 of the connection surface 31a is recessed in the z direction with respect to the first portion 31a1. The non-magnetic layer 24 is fitted in the recess of the first conductive layer 31.

A part of the second conductive layer 41 is in direct contact with the wiring layer 16, and a part of the second conductive layer 41 is in contact with the wiring layer 16 via the non-magnetic layer 24. The first part 41a1 of the connection surface 41a is in direct contact with the wiring layer 16, and the second part 41a2 is in contact with the wiring layer 16 via the non-magnetic layer 24. The second portion 41a2 of the connection surface 41a is recessed in the z direction with respect to the first portion 41a1. The non-magnetic layer 24 is fitted in the recess of the second conductive layer 41.

In the magnetic domain wall movement element 102 according to the second modified example, the first conductive layer 31 and the wiring layer 16 are partly in direct contact with each other and partly in contact with each other via the non-magnetic layer 24. Therefore, the magnetic

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domain wall movement element **102** according to the second modified example also has the same effect as the magnetic domain wall movement element **100**. Further, since the first surface **16a** of the wiring layer **16** is flat, it is possible to suppress the disturbance of the orientation direction of the magnetization of the wiring layer **16** and to prevent the magnetic domain wall **15** from being trapped.

FIG. **9** is a cross-sectional view of the magnetic domain wall movement element **102'** related to another example of the second modified example on the yz plane. The magnetic domain wall movement element **102'** has a different shape from the magnetic domain wall movement element **102** in the non-magnetic layer **24'**.

The non-magnetic layer **24'** is different from the non-magnetic layer **24** in that it has a thickness changing portion **24A'**, and is common to the non-magnetic layer **23**. The non-magnetic layer **24'** has a thickness changing portion **24'A** in which the thickness thereof gradually decreases and a main portion **24'B** in which the thickness thereof is substantially constant. The thickness of the thickness changing portion **24A'** becomes thinner as the distance from the midpoint in the x direction of the non-magnetic layer **24** increases. The thickness of the thickness changing portion **24A'** becomes thinner, for example, as the distance from the ferromagnetic layer **60** increases. The main portion **24'B** is located at a position that overlaps with the ferromagnetic layer **60** when viewed from the z direction. The thickness changing portion **24A'** is located at a position that does not overlap with the ferromagnetic layer **60** when viewed from the z direction.

Also in the magnetic domain wall movement element **102'**, the first conductive layer **31** and the wiring layer **16** are partly in direct contact with each other and partly in contact with each other via the non-magnetic layer **24'**. Therefore, the magnetic domain wall movement element **102'** also has the same effect as the magnetic domain wall movement element **100**. Further, since the non-magnetic layer **24'** has a thickness changing portion **24'**, the magnetic domain wall movement element **102'** results in the same effect as the magnetic domain wall movement element **102**.

Third Modified Example

FIG. **10** is a cross-sectional view of the magnetic domain wall movement element **103** according to the third modified example on the yz plane. The shape of the wiring layer **17** and the positional relationship of the non-magnetic layer **25** of the magnetic domain wall movement element **103** are different from those of the magnetic domain wall movement element **100**. The wiring layer **17** corresponds to the wiring layer **10** described above, and the non-magnetic layer **25** corresponds to the non-magnetic layer **20** described above. The same components as those of the magnetic domain wall movement element **101** in the magnetic domain wall movement element **103** are designated by the same reference numerals, and the description thereof will be omitted.

The non-magnetic layer **25** has a thickness changing portion **25A** and a main portion **25B**. The thickness of the thickness changing portion **25A** becomes thinner as the distance from the midpoint in the x direction of the non-magnetic layer **25** increases. The thickness of the thickness changing portion **25A** becomes thinner, for example, as the distance from the ferromagnetic layer **60** increases.

The main portion **25A** is located at a position that overlaps with the ferromagnetic layer **60** when viewed from the z direction. By extending the thickness changing portion **25A** to a position where it overlaps with the ferromagnetic layer

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60, the rate of change of the inclination angle of the magnetization of the wiring layer **17** on the thickness changing portion **25A** can be made slower than that of the magnetic domain wall movement element **101**. Further, by extending the thickness changing portion **25A** to a position where it overlaps with the ferromagnetic layer **60**, the distance between the ferromagnetic layer **60** and the first and second conductive layers **30**, **40** can be shortened, and the integration of the magnetic domain wall movement element **103** can be achieved.

Further, also in the third modified example, the average thickness of the non-magnetic layer **25** between the first conductive layer **30** or the second conductive layer **40** and the wiring layer **17** is preferably 10 Å or less.

Also in the magnetic domain wall movement element **103** according to the third modified example, the first conductive layer **33** and the wiring layer **17** are partly in direct contact with each other and partly in contact with each other via the non-magnetic layer **25**. Therefore, the magnetic domain wall movement element **103** according to the third modified example also has the same effect as the magnetic domain wall movement element **100**.

Fourth Modified Example

FIG. **11** is a cross-sectional view of the magnetic domain wall movement element **104** according to the fourth modified example on the yz plane. The shapes of the wiring layer **18**, the first conductive layer **32**, the second conductive layer **42**, the non-magnetic layer **51**, and the ferromagnetic layer **61** of the magnetic domain wall movement element **104** are different from those of the magnetic domain wall movement element **101**. The wiring layer **18** corresponds to the wiring layer **10** described above, the first conductive layer **32** corresponds to the first conductive layer **30** described above, the second conductive layer **42** corresponds to the second conductive layer **40** described above, the non-magnetic layer **51** corresponds to the non-magnetic layer **50** described above, and the ferromagnetic layer **61** corresponds to the ferromagnetic layer **60** described above. The same components as those of the magnetic domain wall movement element **101** in the magnetic domain wall movement element **104** are designated by the same reference numerals, and the description thereof will be omitted.

The side surfaces of the first conductive layer **32**, the second conductive layer **42**, the second non-magnetic layer **51**, and the ferromagnetic layer **61** are inclined. Each laminated surface of the wiring layer **18** reflects the shape of the non-magnetic layer **23**.

In the magnetic domain wall movement element **104** according to the fourth modified example, the first conductive layer **32** and the wiring layer **18** are partly in direct contact with each other and partly in contact with each other via the non-magnetic layer **23**. Therefore, the magnetic domain wall movement element **104** according to the fourth modified example also has the same effect as the magnetic domain wall movement element **100**.

Second Embodiment

FIG. **12** is a cross-sectional view of the magnetic domain wall movement element **105** according to the second embodiment on the yz plane. The shape of the wiring layer **19** and the nonmagnetic layer **26** of magnetic domain wall movement element **105** is different from that of the magnetic domain wall movement element **101**. The wiring layer **19** corresponds to the wiring layer **10** described above, and the

non-magnetic layer 26 corresponds to the non-magnetic layer 20 described above. The same components as those of the magnetic domain wall movement element 101 in magnetic domain wall movement element 105 are designated by the same reference numerals, and the description thereof will be omitted.

The non-magnetic layer 26 is in contact with the first surface 19a of the wiring layer 19. The non-magnetic layer 26 is on the first surface 19a of the wiring layer 19. The non-magnetic layer 26 straddles the fixed magnetization region 11, the magnetic domain wall movement region 13, and the fixed magnetization region 12.

The non-magnetic layer 26 extends from a position overlapping the magnetic domain wall movement region 13 in the z direction toward between the fixed magnetization region 11 and the first conductive layer 30 and between the fixed magnetization region 12 and the second conductive layer 40. There is a non-magnetic layer 26 between the fixed magnetization region 11 and the first conductive layer 30 and between the fixed magnetization region 12 and the second conductive layer 40. The non-magnetic layer 26 is made of the same material as the non-magnetic layer 20. The average thickness of the non-magnetic layer 26 between the first conductive layer 30 or the second conductive layer 40 and the wiring layer 19 is preferably 10 Å or less.

The thickness of the non-magnetic layer 26 at a position located between the first conductive layer 30 and the wiring layer 19 is thinner than the thickness of the non-magnetic layer 26 at a position which overlaps the first end t1 of the connection surface 30a of the first conductive layer 30 on the side near the second conductive layer 40 in plan view. The thickness of the non-magnetic layer 26 at a position located between the second conductive layer 40 and the wiring layer 19 is thinner than the thickness of the non-magnetic layer 26 at the position which overlaps the first end t1' of the connection surface 40a of the second conductive layer 40 on the side near the first conductive layer 30 in plan view.

If there is a thin portion of the non-magnetic layer 26 between the first conductive layer 30 and the wiring layer 19 and between the second conductive layer 40 and the wiring layer 19, in this portion the magnetic coupling between the first conductive layer 30 and the wiring layer 19 and the magnetic coupling between the second conductive layer 40 and the wiring layer 19 are strengthened. That is, the invasion of the magnetic domain wall 15 into the fixed magnetization regions 11 and 12 and the disappearance of the magnetic domain wall 15 are suppressed, and the operation of the magnetic domain wall movement element 100 is stabilized. Further, there is no step at the boundary between the fixed magnetization regions 11, 12 and the magnetic domain wall movement region 13, and the operation of the magnetic domain wall movement element 100 is stabilized.

Third Embodiment

FIG. 13 is a cross-sectional view of the magnetic domain wall movement element 106 according to the third embodiment on the yz plane. The magnetic domain wall movement element 106 is different from the magnetic domain wall movement element 100 in that it does not have the second non-magnetic layer 50 and the ferromagnetic layer 60. The same components as those of the magnetic domain wall movement element 101 in magnetic domain wall movement element 106 are designated by the same reference numerals, and the description thereof will be omitted.

The domain wall moving element 106 can be used as an optical modulator. Light L1 is incident on the wiring layer

10, and light L2 reflected by the wiring layer 10 is evaluated. Due to the magnetic Kerr effect, the deflection state of the light L2 reflected at the portion where the orientation direction of magnetization is different is different. The magnetic domain wall movement 106 can be used as an image display device utilizing the difference in the deflection state of the light L2.

Also in the magnetic domain wall movement element 103 according to the third embodiment, the first conductive layer 30 and the wiring layer 10 are partly in direct contact with each other and partly in contact with each other via the non-magnetic layer 20. Therefore, the magnetic domain wall movement element 106 according to the third embodiment also has the same effect as the magnetic domain wall movement element 100.

The preferred embodiments of the present invention have been described in detail above. The characteristic configurations in the respective embodiments and modifications may be combined.

EXPLANATION OF REFERENCES

- 10, 16, 17, 18, 19 Wiring layer
- 10a, 16a, 19a First surface
- 11, 12 Fixed magnetization region
- 13 Magnetic domain wall movement region
- 13A First magnetic domain
- 13B Second magnetic domain
- 15 Magnetic domain wall
- 20, 21, 22, 23, 24, 25, 26 Non-magnetic layer
- 22a, 30a, 40a Connection face
- 23A, 25A Thickness changing portion
- 23B, 25B Main portion
- 30, 31, 32 First conductive layer
- 30a1, 40a1 First portion
- 30a2, 40a2 Second portion
- 40, 41, 42 Second conductive layer
- 50, 51 Second non-magnetic layer
- 60, 61 Ferromagnetic layer
- 90 Insulating layer
- 100, 101, 102, 103, 104, 105, 106, 111, 112 Magnetic domain wall movement element
- 110 First switching element
- 120 Second switching element
- 130 Third switching element
- 200 Magnetic recording array
- st Step
- t1, t1' First end
- What is claimed is:
- 1. A magnetic domain wall movement element comprising:
 - a wiring layer containing a ferromagnetic material;
 - a non-magnetic layer in contact with a first surface of the wiring layer;
 - a first conductive layer connected to the first surface of the wiring layer and containing a ferromagnetic material;
 - a second conductive layer connected to the wiring layer at a distance from the first conductive layer;
 - a first part of a connection face of the first conductive layer;
 - a part of the wiring layer that is in contact with the first part of the connection face;
 - a second part of the connection face other than the first part; and
 - another part of the wiring layer that is in contact with a part of the non-magnetic layer that is in contact with the second part.

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2. The magnetic domain wall movement element according to claim 1, wherein an area of the first part is wider than an area of the second part.

3. The magnetic domain wall movement element according to claim 1, wherein the connection face of the first conductive layer is recessed in a lamination direction, and a part of the non-magnetic layer is fitted in the recess of the connection face.

4. The magnetic domain wall movement element according to claim 1, wherein the first surface of the wiring layer is recessed in a lamination direction, and the non-magnetic layer is fitted in the recess of the first surface.

5. The magnetic domain wall movement element according to claim 1, wherein the non-magnetic layer located between the first conductive layer and the wiring layer becomes thinner as it moves away from a first end of the connection face on a side near the second conductive layer.

6. The magnetic domain wall movement element according to claim 1, wherein an average thickness of the non-magnetic layer between the first conductive layer and the wiring layer is 10 Å or less.

7. The magnetic domain wall movement element according to claim 1, wherein the second conductive layer contains a ferromagnetic material and a part of the wiring layer is in contact with a first part of a connection face of the second conductive layer, and another part of the wiring layer is in contact with a part of the non-magnetic layer which is in contact with a second part of the connection face of the second conductive layer other than the first part.

8. The magnetic domain wall movement element according to claim 1, wherein the second conductive layer contains a ferromagnetic material and a thickness of the non-magnetic layer at a position located between the second conductive layer and the wiring layer is thinner than a thickness of the non-magnetic layer at a position which overlaps a first end of a connection face of the second conductive layer on a side near the first conductive layer in plan view.

9. The magnetic domain wall movement element according to claim 1, further comprising:

- a ferromagnetic layer located above a second surface of the wiring layer opposite the first surface; and
- a second non-magnetic layer located between the ferromagnetic layer and the wiring layer.

10. The magnetic domain wall movement element according to claim 9, wherein the non-magnetic layer has a thickness changing portion that becomes thinner as a distance from the ferromagnetic layer increases and the thickness changing portion does not overlap the ferromagnetic layer when viewed from a lamination direction.

11. The magnetic domain wall movement element according to claim 9, wherein the non-magnetic layer has a thickness changing portion that becomes thinner as a distance from the ferromagnetic layer increases and a part of the thickness changing portion overlaps the ferromagnetic layer when viewed from a lamination direction.

12. A magnetic recording array comprising a plurality of the magnetic domain wall movement elements according to claim 1.

13. A magnetic domain wall movement element, comprising:

- a wiring layer containing a ferromagnetic material;
- a non-magnetic layer in contact with a first surface of the wiring layer;

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a first conductive layer connected to the first surface of the wiring layer and containing a ferromagnetic material; and

a second conductive layer connected to the wiring layer at a distance from the first conductive layer,

wherein the first conductive layer is connected to the wiring layer via the non-magnetic layer, and

a thickness of the non-magnetic layer at a position located between the first conductive layer and the wiring layer is thinner than a thickness of the non-magnetic layer at a position which overlaps a first end of a connection face of the first conductive layer on a side near the second conductive layer in plan view.

14. The magnetic domain wall movement element according to claim 13, wherein the non-magnetic layer located between the first conductive layer and the wiring layer becomes thinner as it moves away from the first end of the connection face on the side near the second conductive layer.

15. The magnetic domain wall movement element according to claim 13, wherein an average thickness of the non-magnetic layer between the first conductive layer and the wiring layer is 10 Å or less.

16. The magnetic domain wall movement element according to claim 13, wherein the second conductive layer contains a ferromagnetic material and a part of the wiring layer is in contact with a first part of a connection face of the second conductive layer, and another part of the wiring layer is in contact with a part of the non-magnetic layer which is in contact with a second part of the connection face of the second conductive layer other than the first part.

17. The magnetic domain wall movement element according to claim 13, wherein the second conductive layer contains a ferromagnetic material and a thickness of the non-magnetic layer at a position located between the second conductive layer and the wiring layer is thinner than a thickness of the non-magnetic layer at a position which overlaps a first end of a connection face of the second conductive layer on a side near the first conductive layer in the plan view.

18. The magnetic domain wall movement element according to claim 13, further comprising:

- a ferromagnetic layer located above a second surface of the wiring layer opposite the first surface; and
- a second non-magnetic layer located between the ferromagnetic layer and the wiring layer.

19. The magnetic domain wall movement element according to claim 15, wherein the non-magnetic layer has a thickness changing portion that becomes thinner as a distance from the ferromagnetic layer increases and the thickness changing portion does not overlap the ferromagnetic layer when viewed from a lamination direction.

20. The magnetic domain wall movement element according to claim 18, wherein the non-magnetic layer has a thickness changing portion that becomes thinner as a distance from the ferromagnetic layer increases and a part of the thickness changing portion overlaps the ferromagnetic layer when viewed from a lamination direction.

21. A magnetic recording array comprising a plurality of the magnetic domain wall movement elements according to claim 13.

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